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The composite roadwheel is comprised of glass/epoxy composite insert, produced by wet filament winding followed by compression molding at high temperature to cure the matrix. A wet filament wound graphite/epoxy stiffening ring is bonded to the composite wheel separately. Stainless steel inserts are installed at the interface between the composite and the vehicle hub shaft to resist creep effects.

Four (4) roadwheels were tested on two (2) test vehicles at AVTB, Camp Pendleton, CA. During feasibility testing, two roadwheels failed after 7.9 hours of operation and the other two (2) wheels failed at 25.6 hours of operation.

Failure inspection indicated disbonding between the graphite stiffening ring and the fiberglass composite insert as the major cause of failure during high speed wheel maneuvering.

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PHASE I

FABRICATION AND FEASIBILITY TESTING
OF THE COMPOSITE ROADWHEEL FOR THE
LVT-7 AMPHIBIAN VEHICLE

Prepared under Contract No. N00167-85-C-0126
for David Taylor Naval Ship R & D Center
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ABSTRACT

A composite roadwheel for the United States Marine Corps LVT-7 Amphibian Vehicle was designed and manufactured by Compositek Engineering Corporation under Government Contract No. N00167-85-C-0126.

The composite roadwheel is comprised of glass/epoxy composite insert, produced by wet filament winding followed by compression molding at high temperature to cure the matrix. A wet filament wound graphite/epoxy stiffening ring is bonded to the composite insert. A urethane tire and wear plate are molded to the composite wheel separately. Stainless steel inserts are installed at the interface between the composite and the vehicle hub shaft to resist creep effects.

Four (4) roadwheels were tested on two (2) test vehicles at AVTB, Camp Pendleton, California. During feasibility testing, two roadwheels failed after 7.9 hours of operation and the other two (2) wheels failed at 25.6 hours of operation.

Failure inspection indicated disbonding between the graphite stiffening ring and the fiberglass composite insert as the major cause of failure during high speed wheel maneuvering.

Design and process changes to improve producibility and durability are described in this report.

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1.0 INTRODUCTION

This report documents the efforts conducted under Phase I, Tasks II and III of Contract N00167-85-C-0126 for the fabrication and field testing of composite roadwheels for the Marine Corp LVT-7 Assault Amphibian Vehicle. The report completes the technical requirements within the Phase I scope of work.

Four (4) composite roadwheels were fabricated in early 1987 and subjected to feasibility testing at the Marine Corp Amphibian Vehicle Test Branch (AVTB) at Camp Pendleton, California. This report describes the results of these tests, and outlines the recommended approach to the continued development of the composite roadwheel.

2.0 DISCUSSION

2.1 FABRICATION

2.1.1 Manufacture Sequence and Procedure.

The manufacturing approach used to produce the composite wheels is based on filament winding and compression molding. This approach was chosen over hand lay-out or other methods due to its suitability for high quality and high volume production. Following design approval of the composite roadwheel configuration by the Government Contract Officer, four-slide compression molding tool, an aluminum winding mandrel, and two (2) ring mandrels, Figures 1 through 4, were designed and fabricated.

CEC's numerically-controlled four (4) axis filament winding machine was used to lay hoop direction filaments onto the ring mandrels. A mechanically controlled 3-axis polar winding machine was used to wind the fibers on the roadwheel winding mandrel. The wound preform insert (with mandrel) was slit into two halves to produce two wheel structures.

The compression molding tool was installed in CEC's 300 ton hydraulic press which contain integral oil-heated platens. The preform insert was transferred into the four-slide compression molding tool. The mold was closed, temperature and pressure were gradually increased and maintained at 350F and 900 psi, respectively.

Final curing of the fiberglass insert was performed in the molding tool. The fiberglass insert and graphite stiffening ring were machined to size. The stiffening ring and hub bushings were bonded to the insert. The assembly was shipped to Kryptonics, Inc., Boulder, Colorado for the urethane tire/wear plate molding.

2.1.2 Filament-Winding

Winding of the fiberglass composite insert was successfully performed. CEC's 3-axis mechanically controlled polar winding machine was used to wind the insert, Figure 5 (two inserts wound simultaneously). The winding consists of 10 layers of polar winding with an average winding angle of 23.5 degrees, and 6 layers of hoop winding at the rim section, Figure 6. Total winding time was approximately 4 hours.

The fiberglass triangle rings, Figure 7, and the graphite stiffening ring, Figure 8, were wound by using CEC's 4-axis numerical controlled helix winding machine. The winding mandrel was designed to wind two pieces at a time. The triangle ring was used during fiberglass insert winding to fill the corner section, Figure 9. The rings were installed on the corner areas then overwrapped with polar windings. Total winding time to complete two triangle rings and two stiffening rings was approximately 3 hours.

Following the polar winding operation, the mandrel was removed from the winding machine and the uncured fiberglass was slit at the center to form two insert pieces, Figures 10 and 11. The first half was transferred to the 300-ton press for compression molding; the second half was vacuum bagged and stored in the freezer for the next molding.

2.1.3 Molding

The molding tool consists of four lateral slides ("jaws") to form the rim profile, Figure 12, and a top plate, Figure 13, to form the profile of the dish and hub sections. Due to the nature of polar winding, fiber stack-up at the hub and dish region was thicker than calculated. Consequently, the top molding plate could not be closed completely due to the stackup problem during the molding operation. The mold was cycled from open to close several times prior to heat-up such that any problem areas could be repaired with the uncured material.

Heating of the mold was achieved by external heating oil flowing through each mold section. Mold temperature was gradually increased to 350F and maintained for 4 hours under pressure until the part was completely cured, Figure 14. No free standing post cure of the part was required. Upon inspection of the cured parts, some surface voids at the transition area between the rim and dish was evidenced due to the small radius at the corner. Several resin starved areas also were evident due to excessive pressure applied between the upper plate and the mandrel. As a consequence, the mandrel was deformed in the area outward of the hub, thereby, resulting in a greater part thickness. Despite the problem mentioned above, the general quality of the molding was good, and the decision was made to complete all four wheels. Figures 15 through 17 present the molded inserts.

2.1.4 Machining and Bonding

Final machining of the roadwheel rim and hub, Figure 18, was performed. Drawing dimensional requirements were achieved except in the deformed mandrel area. Thickness in this area was up to 0.140 inch oversize from the specified callout. Drilling and counterboring of the hub bushing holes was performed. Inspection of the part after machining indicated no visible signs of damage or cracks throughout the machined areas.

The stiffening ring was machined to allow a 1 degree tapered bond line with the composite insert. Bonding of the stiffening ring to the insert was performed with room temperature cured paste adhesive. Bonding of the center press fitted bushings also was smooth without any problems. Figure 19 presents the completed insert prior to tire molding.

2.1.5 Urethane Tire Molding

Molding of the urethane tire was performed at Kryptonik Co., Boulder, Colorado. The fiberglass inserts were sandblasted and two coats of primer were applied on the rim section to ensure quality bonding, Figure 20. The inserts were heated to 250F for two to three hours hold period, then placed in the mold for urethane tire molding, Figures 21, 22 and 23. The mold was rotated to release entrapped air in the urethane, Figure 24. Parts were removed from the mold after one hour at room temperature and placed in an oven at 175F for 12 hours. The wear plate was molded separately in accordance with the same procedure, Figure 25. The molding material used was Kryptonik's High Temperature Polyurethane X0110. Completed roadwheels are shown in Figures 26 and 27.

2.1.6 Weight

The actual weight breakdown for the Phase I Roadwheel Design is as follows:

Fiberglass/Epoxy Molded Insert	23.5
Graphite/Epoxy Stiffening Ring	4.3
Stainless Steel Bushings (10)	1.4
Urethane Tire/Wear Plate	<u>18.6</u>
TOTAL COMPONENT WEIGHT	47.8

2.2 FIELD TESTING

2.2.1 Installation

Field vehicle testing of the Phase I Composite Roadwheel was carried out by the U. S. Marine Corps Amphibian Vehicle Test Branch at Camp Pendleton, California, using Vehicle ICT-3 and TEP-5. Testing was performed in accordance with the Sprocket Carrier Master Test Plan, sections 2.4.3 and 2.4.4, per the Contracting Officer Technical Representative instructions.

The composite roadwheels were installed onto the test vehicle by USMC Personnel using the normal procedure and tools, Figures 28 and 29. No significant problems were observed during the installation. Roadwheels S/N 608-01 and 608-02 were installed on test vehicle ICT-3 at locations 2 and 4 of the six (6) track wheels, Figures 30 and 31. S/N 605-01 and 607-02 were installed on test vehicle TEP-5 at location 1 and 6 of the six (6) track wheels, Figure 32.

2.2.2 Feasibility and Durability Testing

The feasibility testing phase consisted of 25 hours running time at representative speeds on a 25-mile course consisting of paved road, sandy beach, and rock cross-country terrain, Figures 33 through 36. Upon satisfactory completion of feasibility testing, the composite roadwheels would begin the 100 hour durability testing.

Roadwheels S/N 608-01 and 608-02 failed after 25.6 hours of operation. Roadwheels S/N 605-01 and 607-02 failed after 7.9 hours of operation. The modes of failure are discussed in the following sections.

2.2.3 Discussion of Failure

As a result of the failure inspections, modes of failure were: separation of the graphite stiffening ring from the molded fiberglass wheel; delamination of the hub and rim sections; and, separation of urethane wear plate.

1. S/N 608-01 - Figures 37 and 38

This composite roadwheel operated 25.6 hours and approximately 330 miles. The failure analysis indicated poor bonding resulted in the loss of the stiffening ring during vehicle operation. Since vehicle operations continued after stiffening ring bond failure, extensive delamination and damage occurred in the hub, rim and wear plate areas.

2. S/N 608-02 - Figures 39 and 40

This composite roadwheel did not show significant structural damage during the 25.6 hours of operation. However, partial debonding occurred between the urethane tire and the fiberglass insert. This wheel currently remains operable.

3. S/N 605-01 - Figures 41 and 42

The roadwheel failed after 7.9 hours of operation. The failure mode was a separation of the urethane wear plate, and a partial debonding of the stiffening ring. As for roadwheel S/N 608-01, continued operation after failure resulted in delamination of the fiberglass insert at the hub section.

4. S/N 607-02 - Figures 43, 44 and 45

The failure mode of this wheel was similar to roadwheel S/N 608-01. The composite roadwheel lost the stiffening ring during operation and, subsequently, resulting in delamination at the hub area.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 STIFFENING RING

Although the failures experienced in the testing phase are disappointing, the encouraging observation is that the roadwheels did not fail due to laminate integrity or gross design error. Since the cause of failure was related to the bonding operation of the ring to the fiberglass inserts, solutions to this problem are achievable.

A short term solution would be to add mechanical locking pins acting as a shear restraint for the two pieces, and use of film adhesive to bond the components together. This approach would add a slight amount of weight to the roadwheel, however, an increase in manufacturing cost would result due to the additional machining operations. Tooling modification would be minimal.

A long term solution for this problem would be a re-design of the winding mandrel to allow winding of the stiffening ring and composite insert as a one piece structure. This would require a new collapsible mandrel and a modification to the existing manufacturing process. Although tooling cost increased for design and fabrication of the new winding mandrel, the potential cost savings per unit may be close to 50 percent due to a decrease in the machining and fabrication effort.

3.2 CRACKING AT HUB

Cracking and delamination was observed around the machined outside surface of the hub area and the mounting holes. This delamination and cracking was caused by excessive roadwheel deflections after loss of the graphite stiffening ring. It has been learned from the Marine Corps Composite Sprocket Carrier Program that continuous fibers from the hub to the free edge of the rim could extend the fatigue life approximately 3 to 4 times. It is our recommendation to modify the hub section thickness configuration in order to allow for continuous fibers.

3.3 URETHANE TIRE/WEAR PLATE

The urethane wear plate which is molded separately from the urethane tire cannot resist the track horn impact forces. The urethane to fiberglass molded bond does not possess sufficient peel strength properties to overcome the peeling forces during operational contact. This problem was addressed during the design phase, however, due to the legal problems, the wear plate has to be molded separately.

CEC recommends molding of the urethane tire and wear plate as a one piece structure such that forces imparted to the wear plate could be transferred into the urethane tire and reacted in shear. Otherwise, the solution would require the bonding of a metallic wear plate to the fiberglass insert.

3.4 SUMMARY

The results of the feasibility testing was less than expected but still encouraging. The failure modes are viewed as minor and resolvable. It is our opinion that with the proposed tooling and process modifications the performance of the composite roadwheel will significantly improve. It appears that a 20 percent weight savings can be achieved over the current metallic configuration.

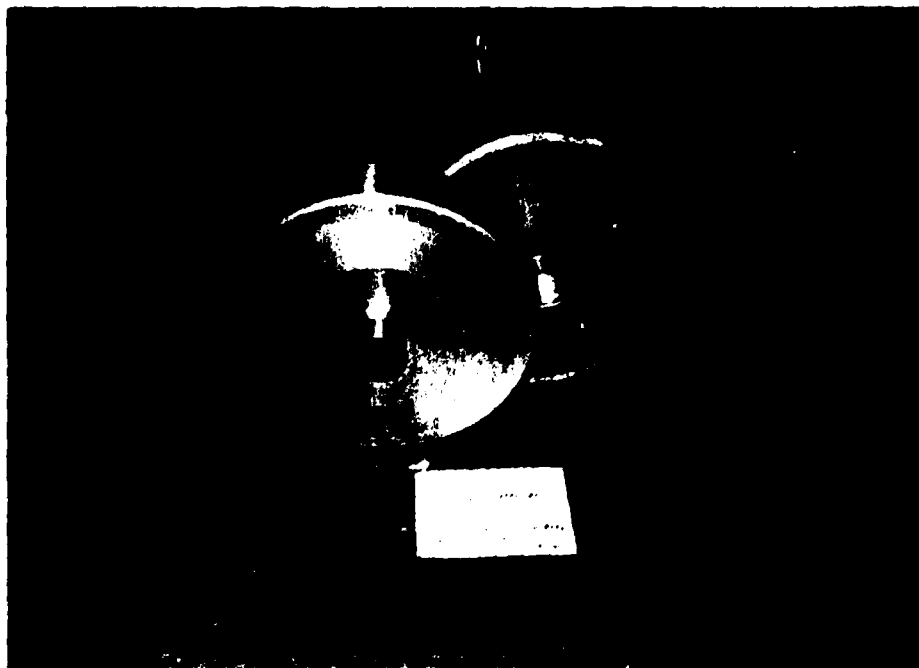


Figure 1. Composite Insert Winding Mandrel

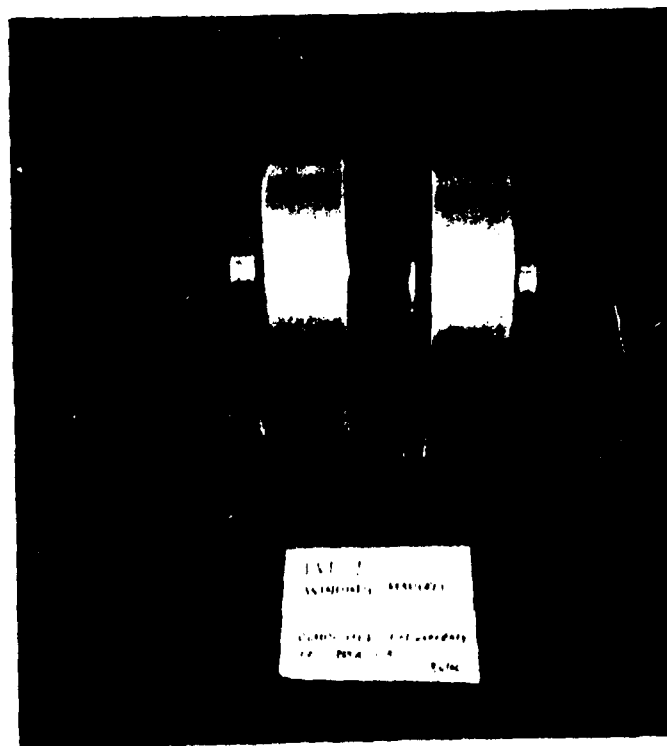


Figure 2. Composite Insert Winding Mandrel

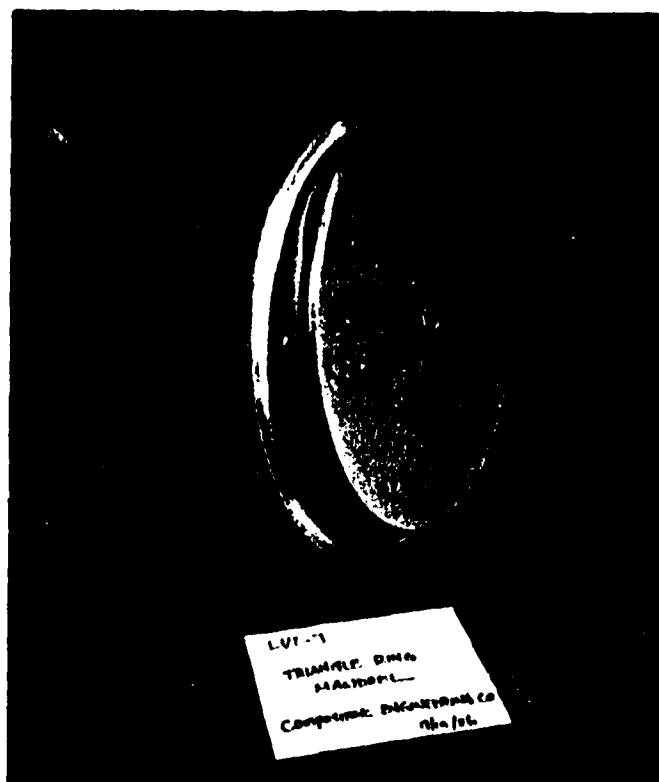


Figure 3. Triangle Ring Winding Mandrel

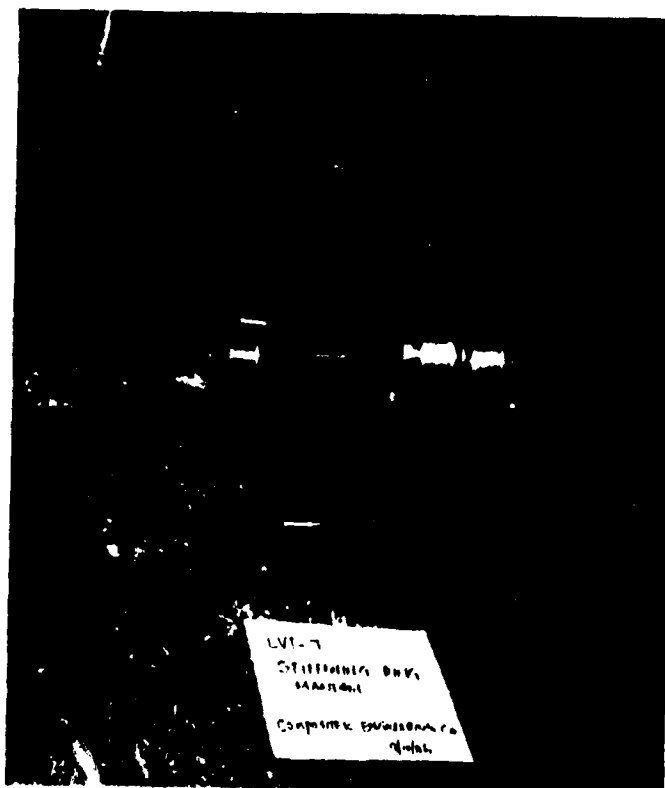


Figure 4. Stiffening Ring Winding Mandrel



Figure 5. 3-Axis Polar Winding Machine

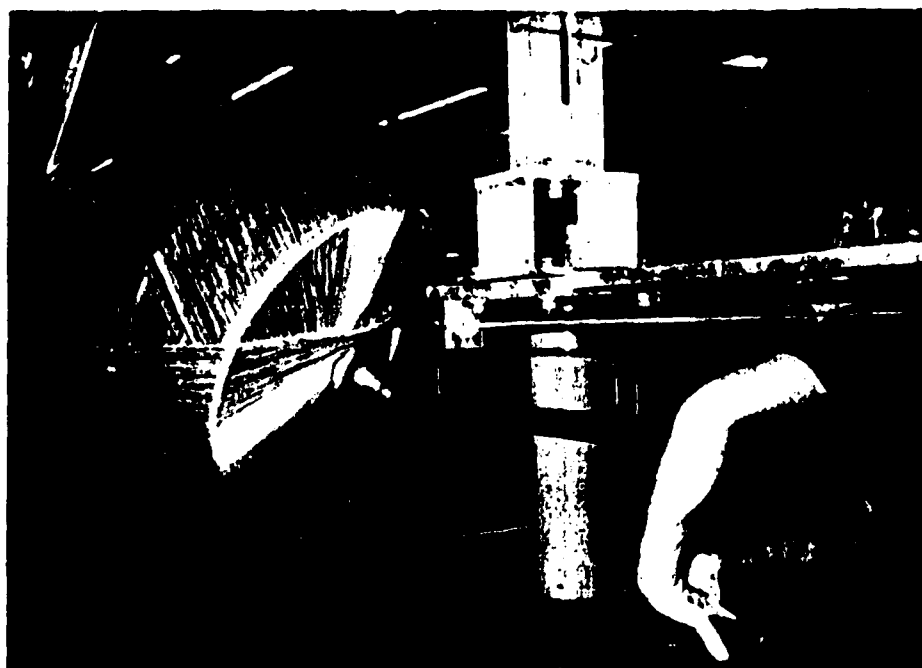


Figure 6. Polar Winding Roadwheel Fiberglass Insert

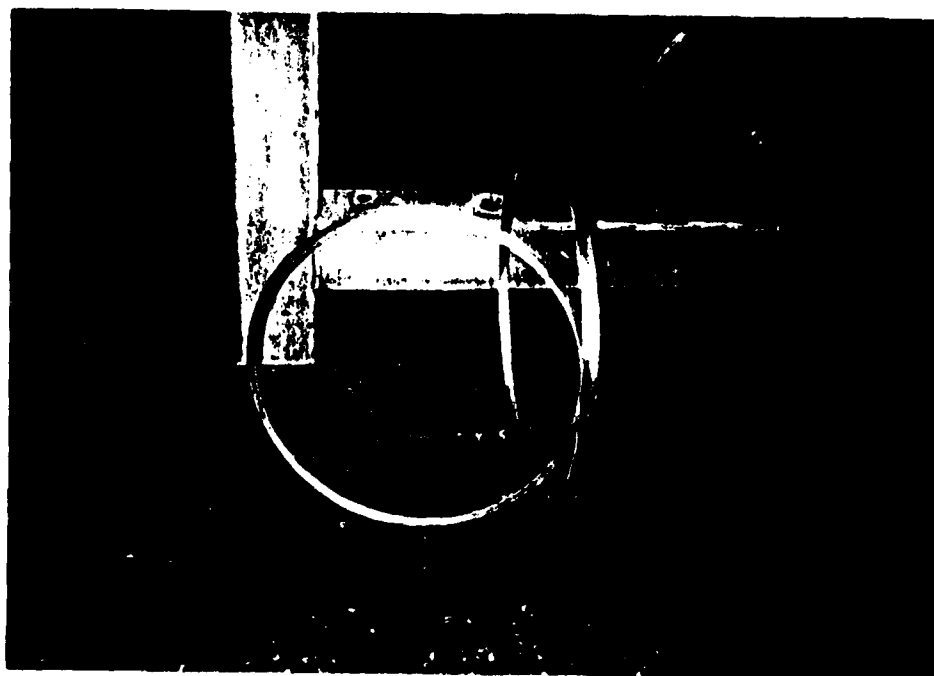


Figure 7. Fiberglass Triangle Rings



Figure 8. Graphite Stiffening Ring

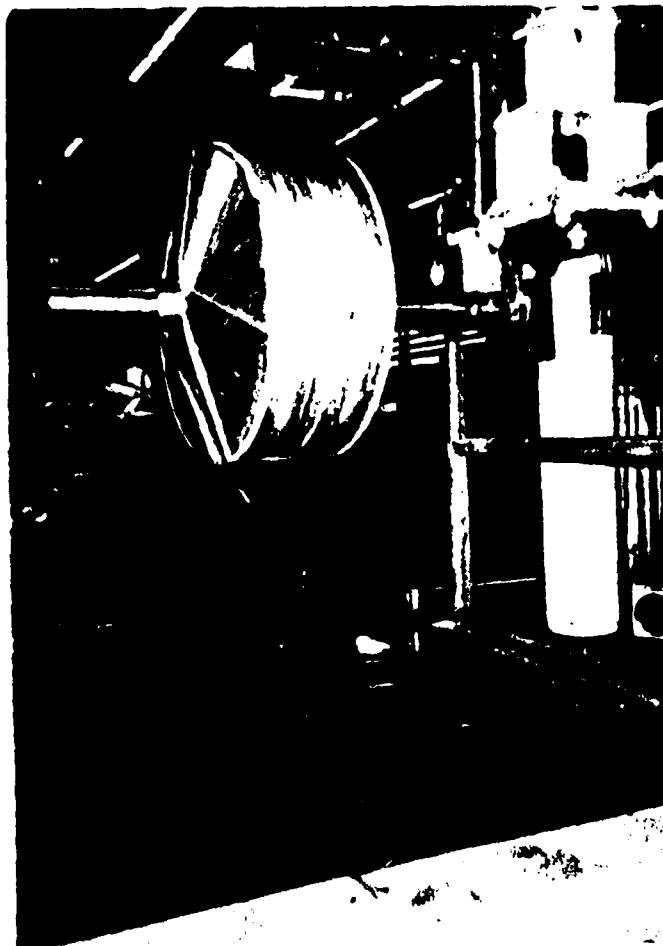


Figure 9. Triangle Ring Installation

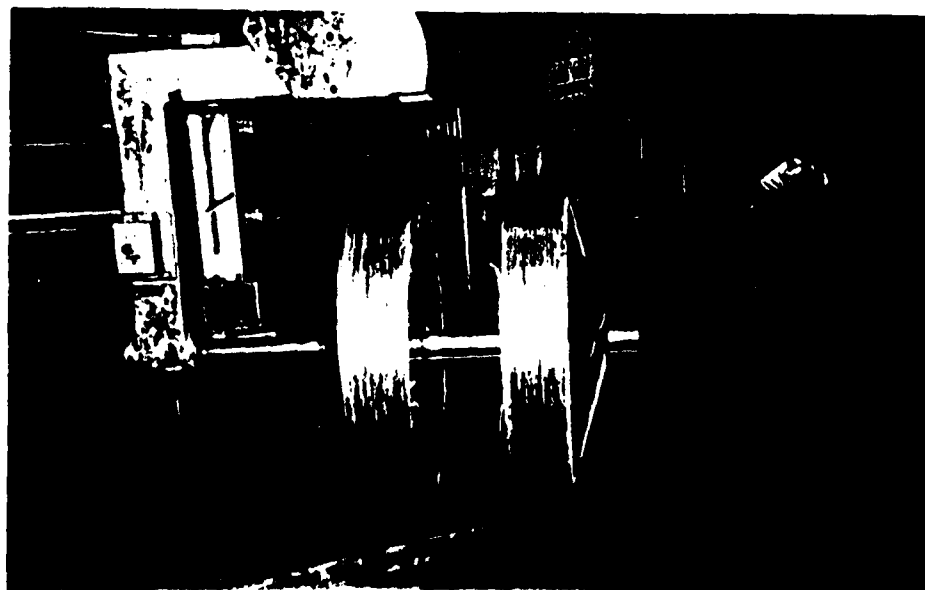


Figure 10. Separation of winding mandrel to yield two preforms.

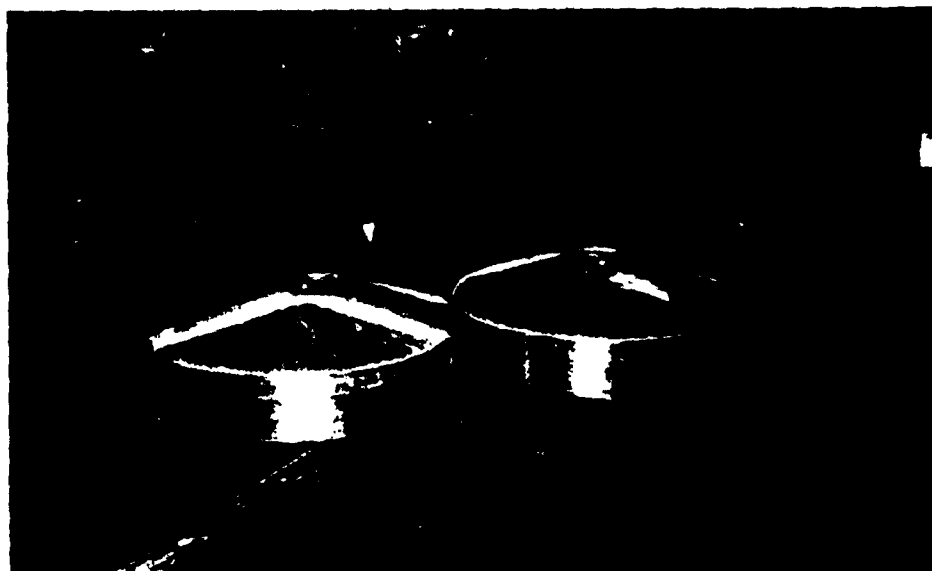


Figure 11. Shell preforms after slitting.

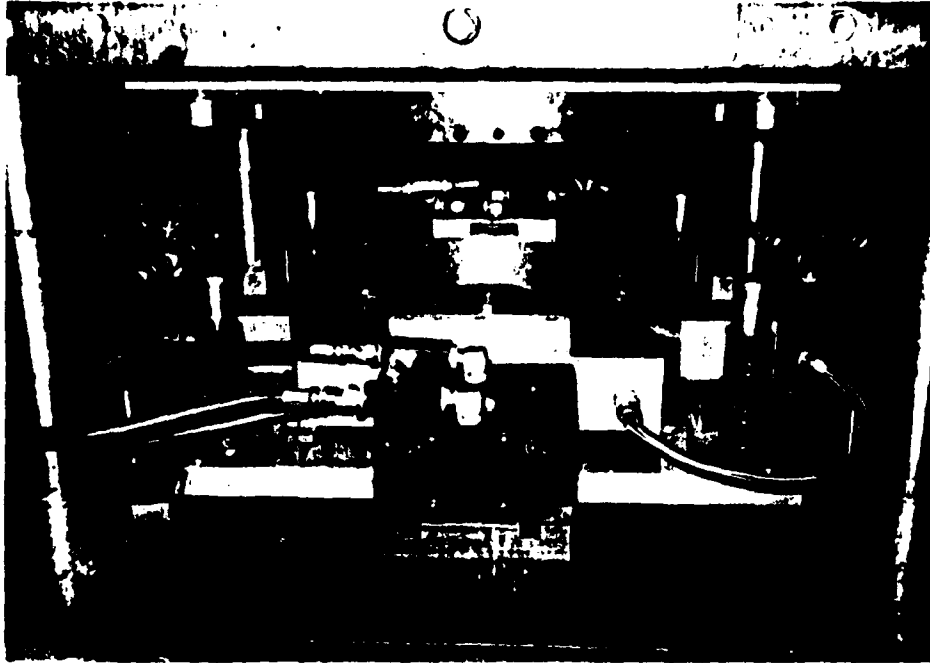


Figure 12. Compression Molding Tool - Bottom Plate



Figure 13. Compression Molding Tool - Top Plate

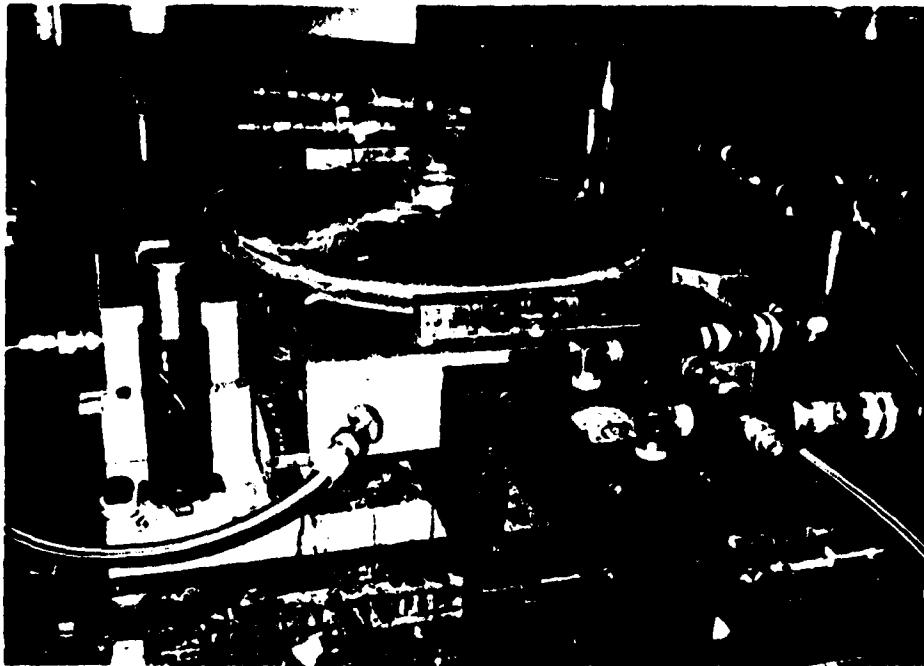


Figure 14. Compression Molding of Fiberglass Insert.

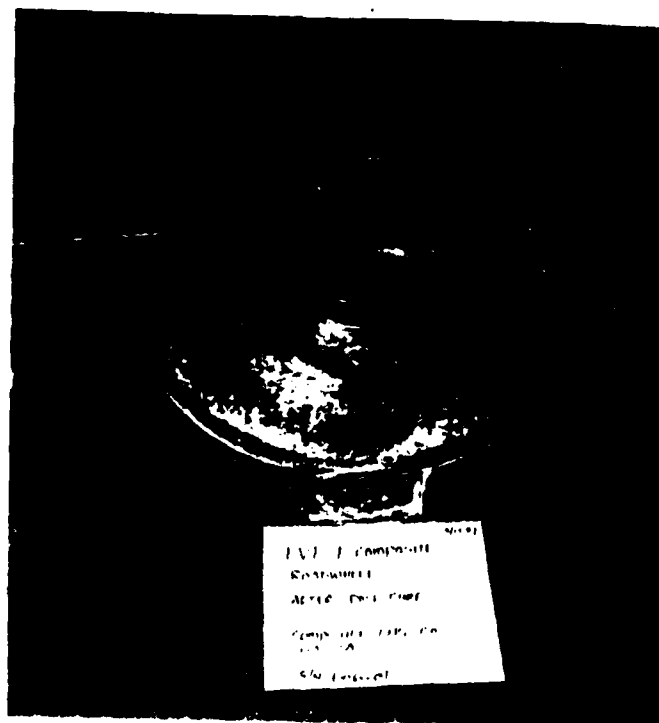


Figure 15. Molded Fiberglass Insert

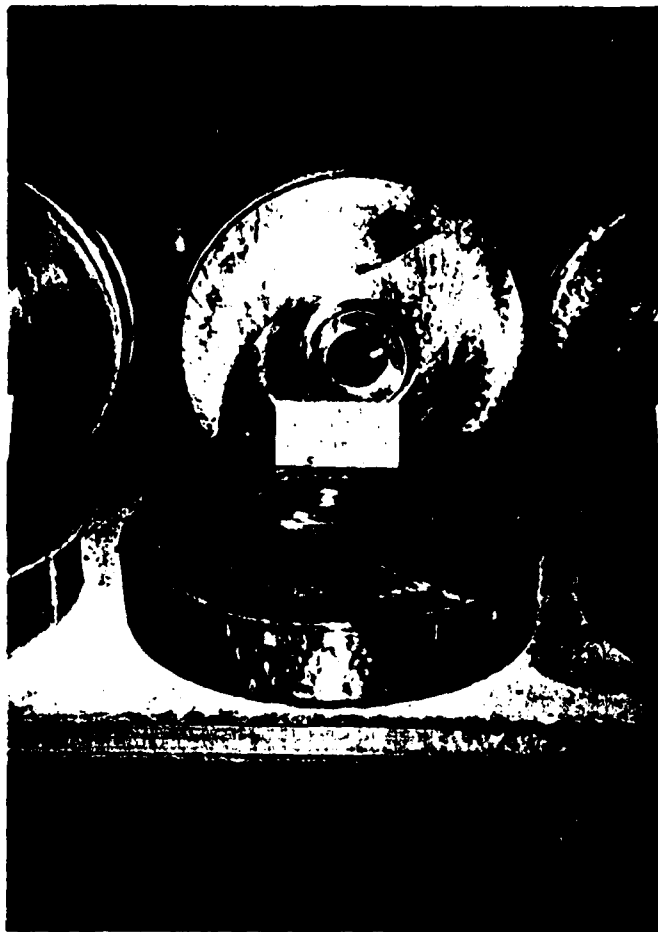


Figure 16. Molded Fiberglass Insert

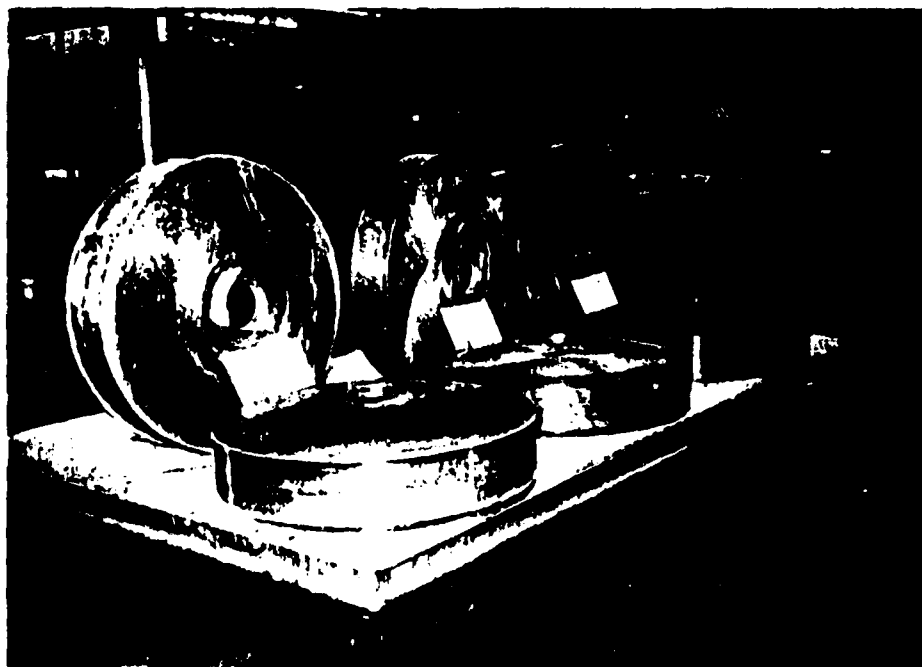


Figure 17. Molded Fiberglass Insert

Figure 18. Composite
Insert
Machining

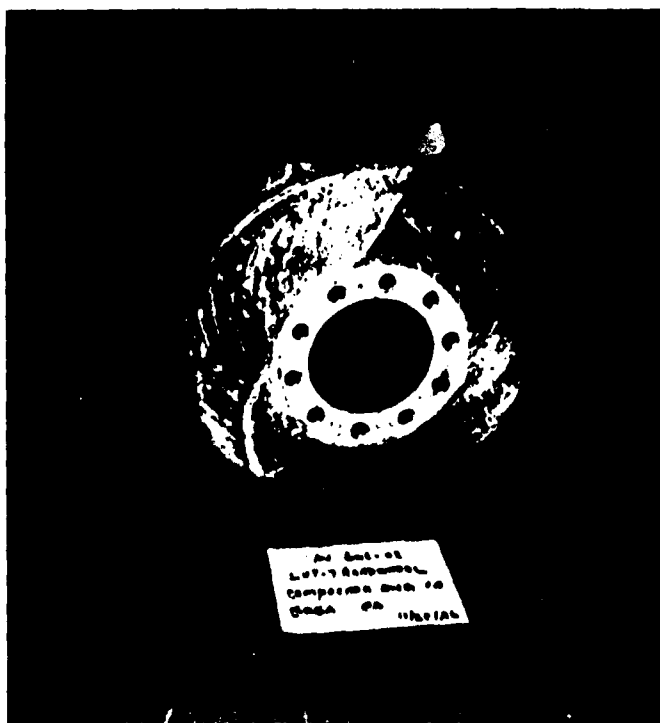
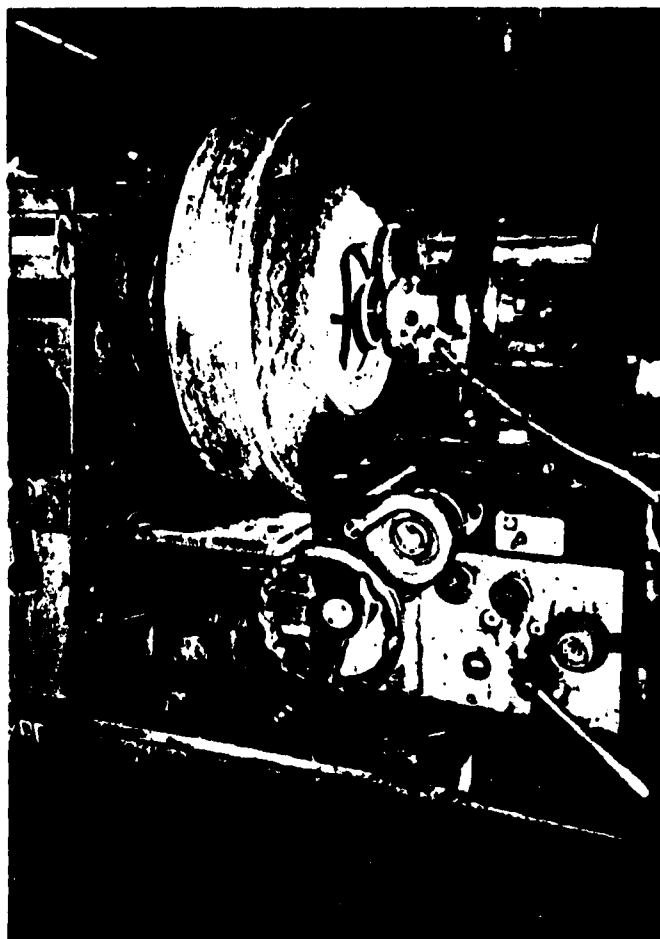


Figure 19. Completed
Composite
Insert



Figure 20. Priming of Composite Insert



Figure 21. Urethane Tire Molding Mandrel

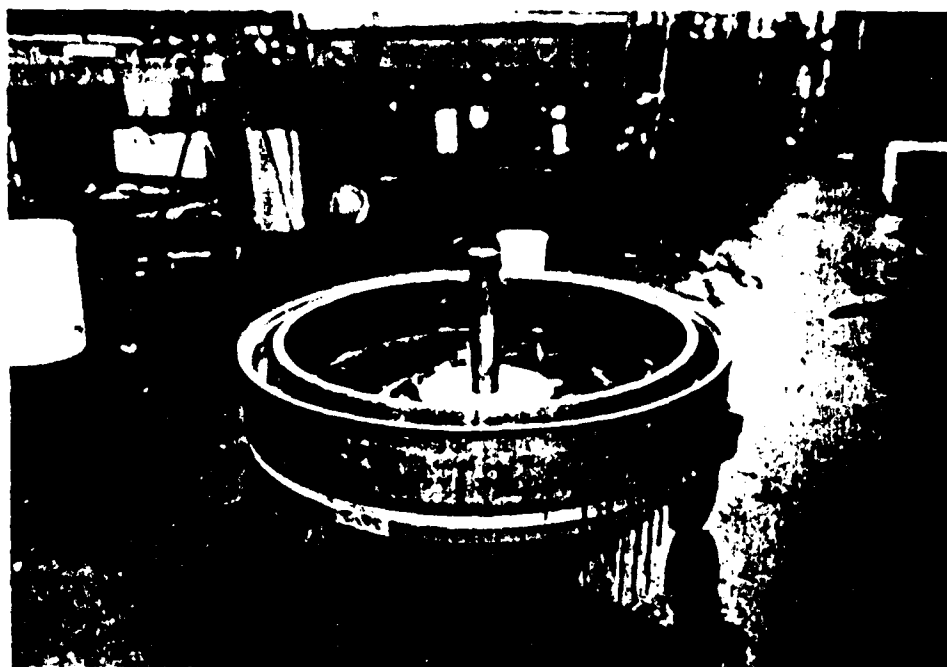


Figure 22. Urethane Tire Molding Mandrel with Insert

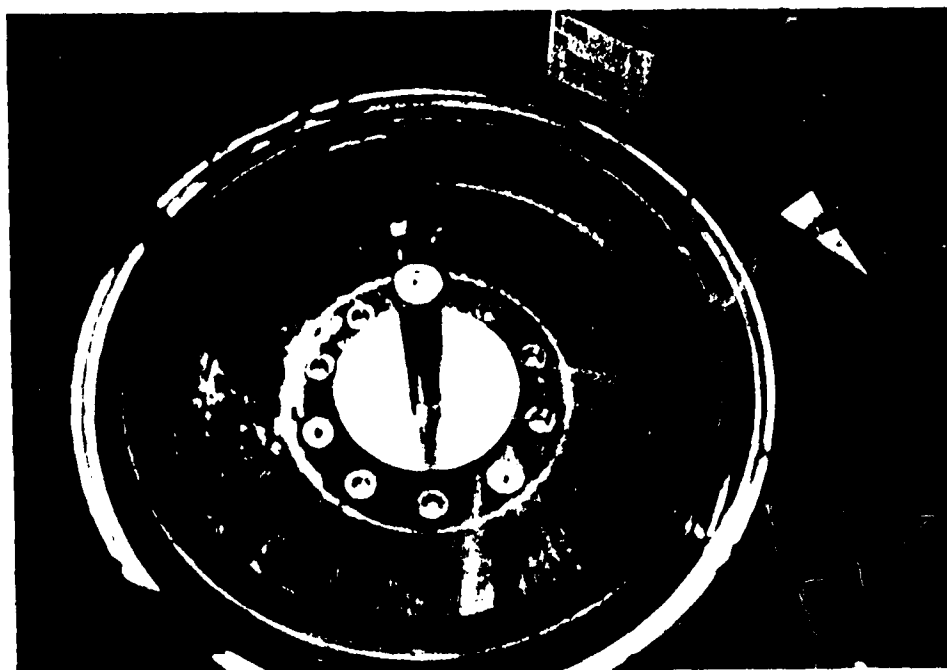


Figure 23. Urethane Tire Molding - Pull Urethane



Figure 24. Urethane Tire Molding - Mandrel Rotating



Figure 25. Molding Urethane Wear Plate

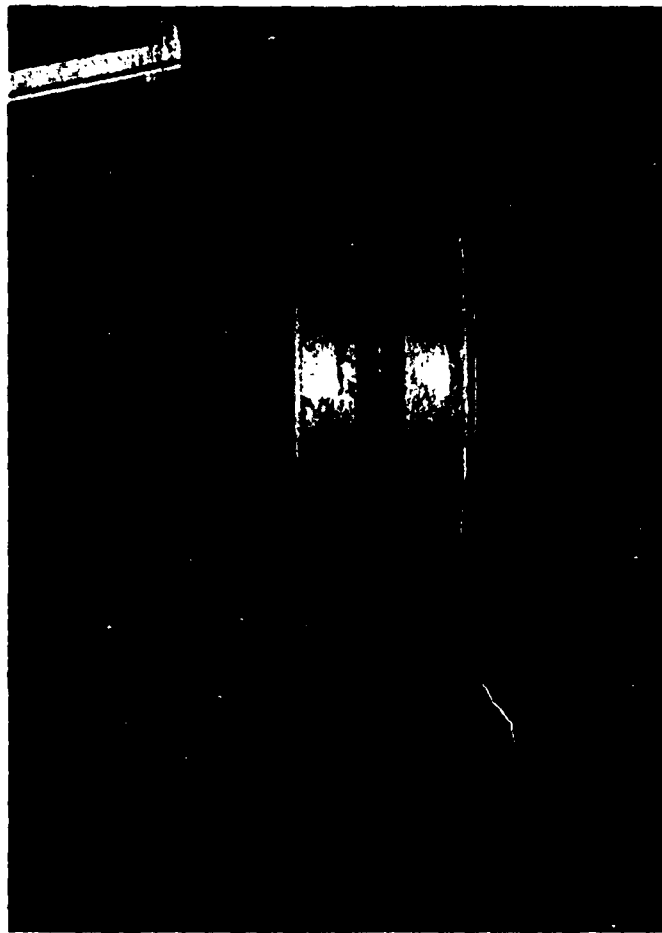


Figure 26. Composite Roadwheel - Prototype Units

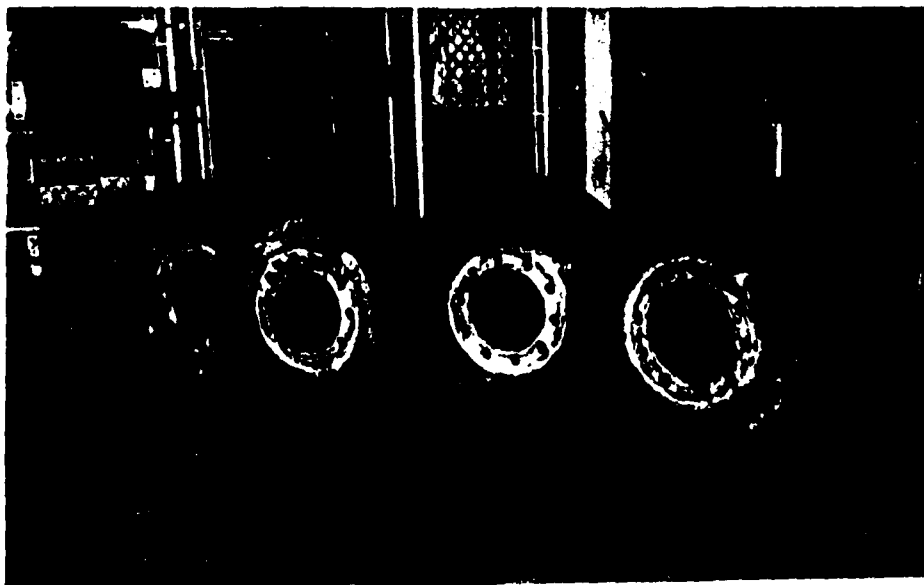


Figure 27. Composite Roadwheel - Prototype Units



Figure 28. Roadwheel Installation - S/N 605-01



Figure 29. Roadwheel Installation - S/N 607-02

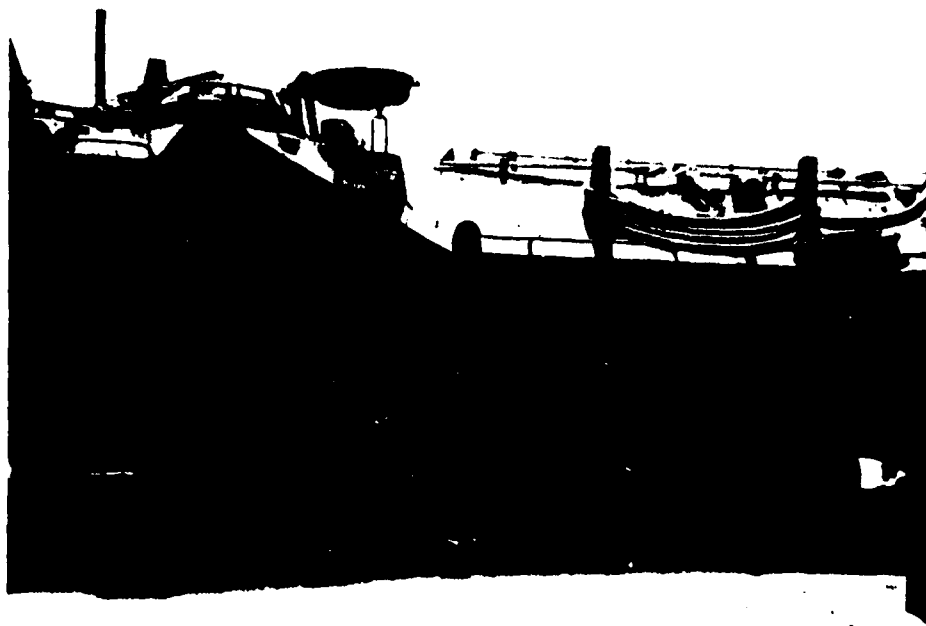


Figure 30. Test Vehicle ICT-3 with Composite Roadwheel.

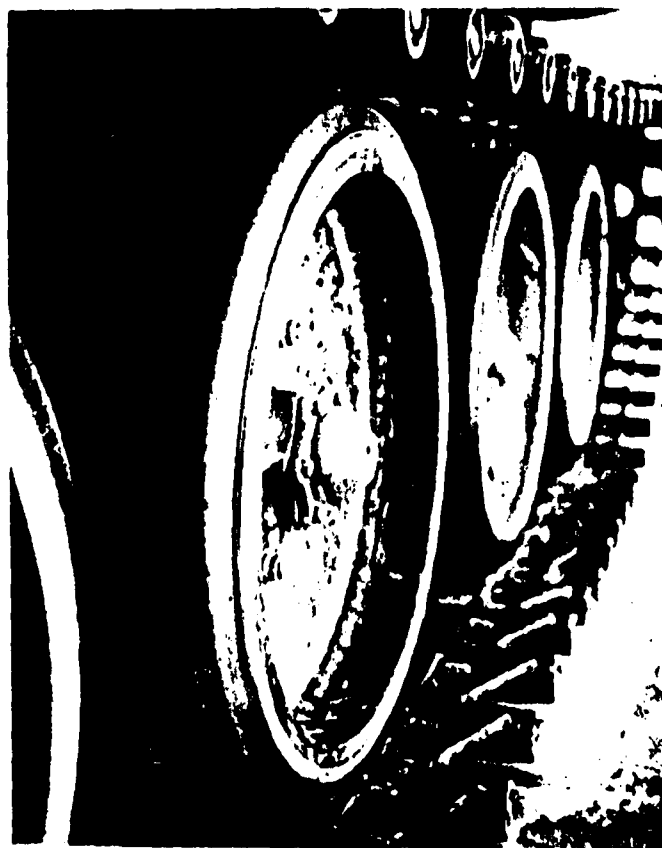


Figure 31. Composite Roadwheel - S/N 608-02



Figure 32. Test Vehicle TEP-5 with Composite
Roadwheel - S/N 605-01



Figure 33. Composite Roadwheel Field Testing - Sea Water

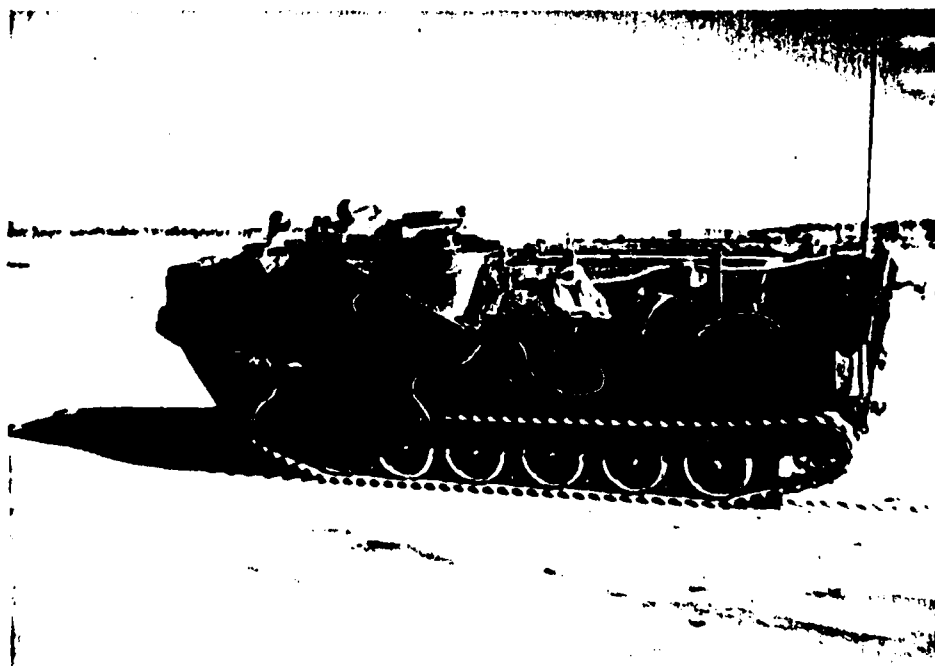


Figure 34. Composite Roadwheel Field Testing - Sandy Beach

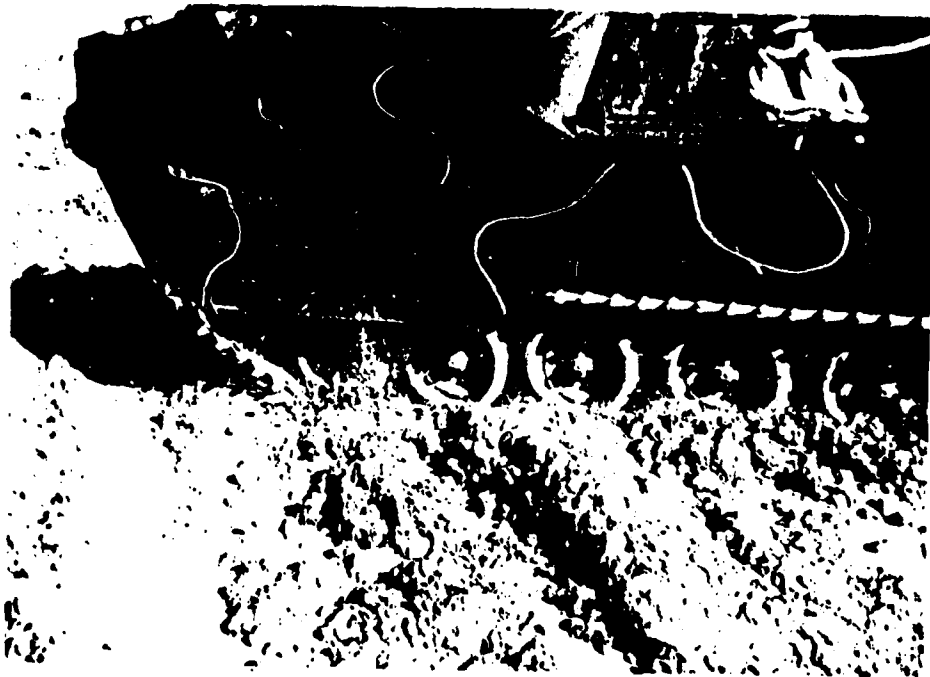


Figure 35. Composite Roadwheel Field Testing - Mud

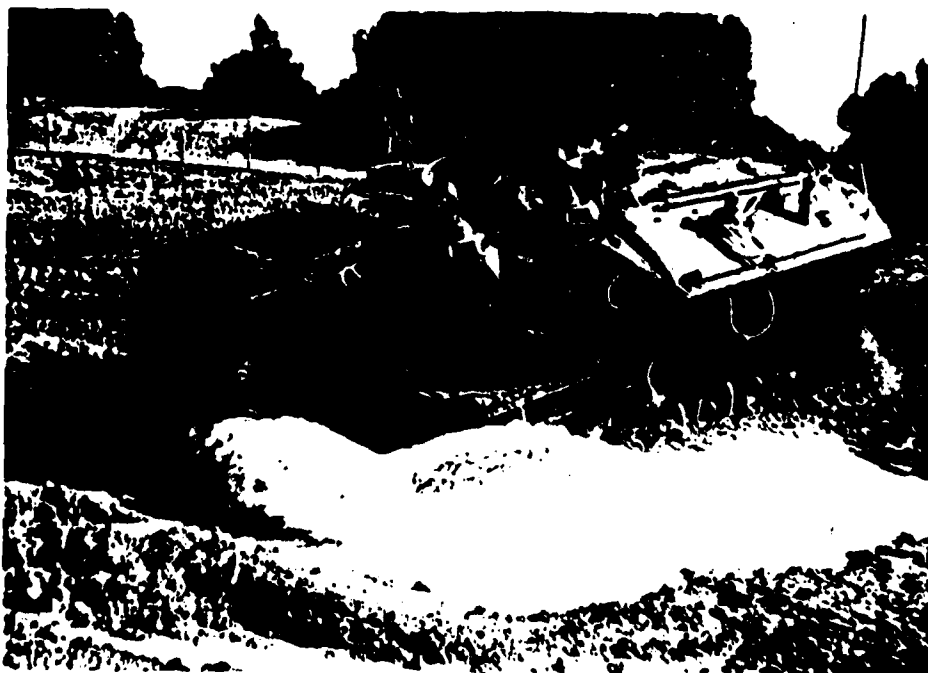


Figure 36. Composite Roadwheel Field Testing -
Mud and Sea Water

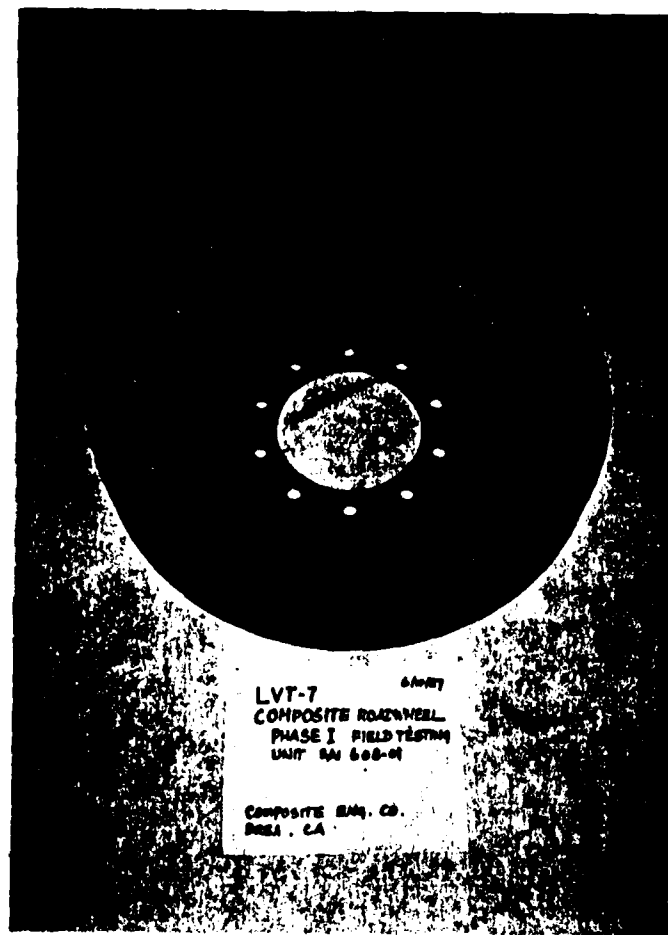


Figure 37. S/N 608-01 after Field Testing

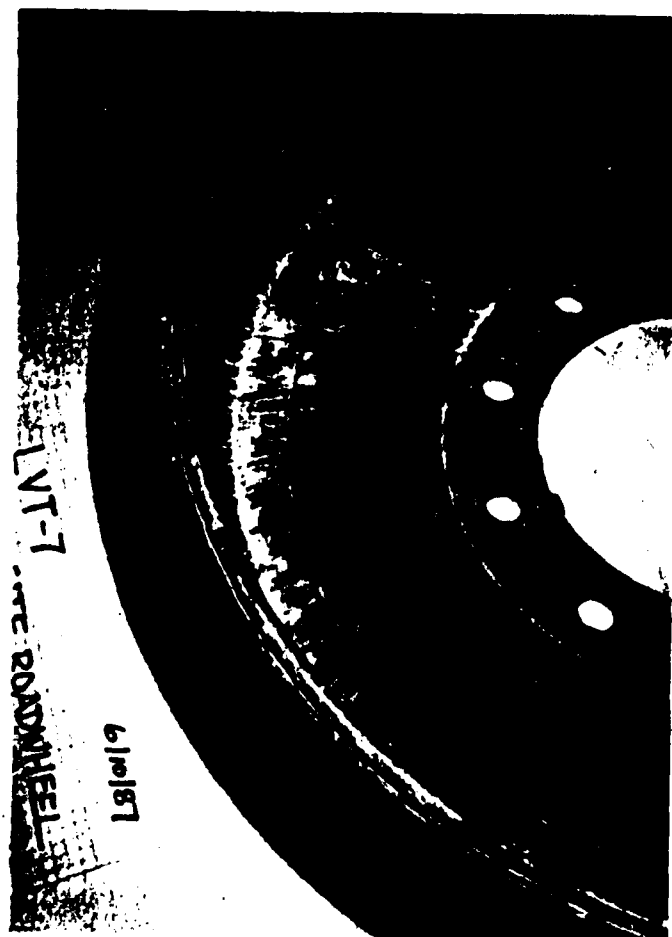


Figure 38. S/N 608-01 after Field Testing -
Rim Delamination

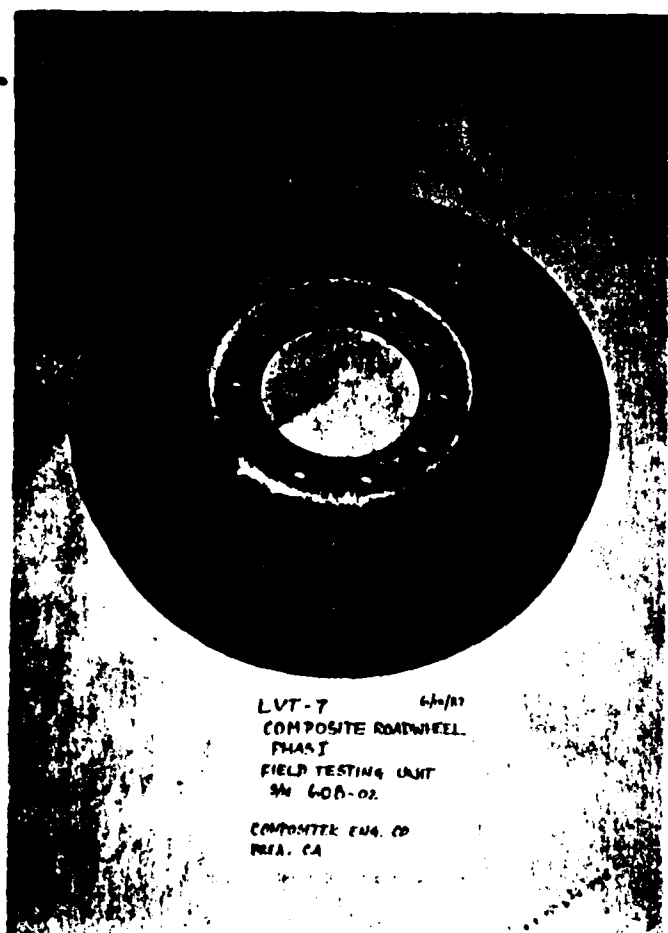


Figure 39. S/N 608-02 after
Field Testing -
outside view.

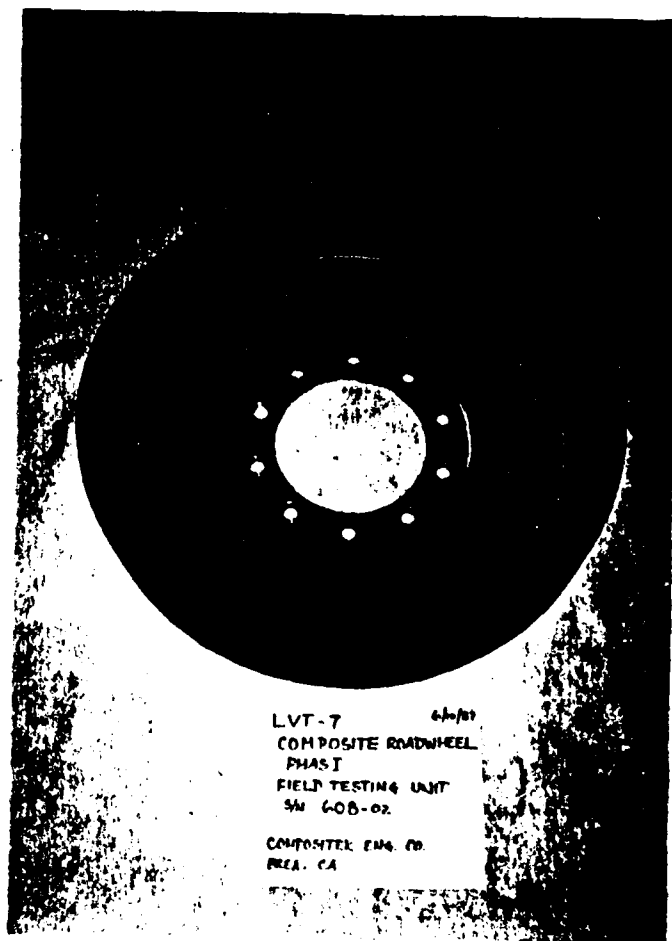


Figure 40. S/N 608-02 after
Field Testing -
inside view.

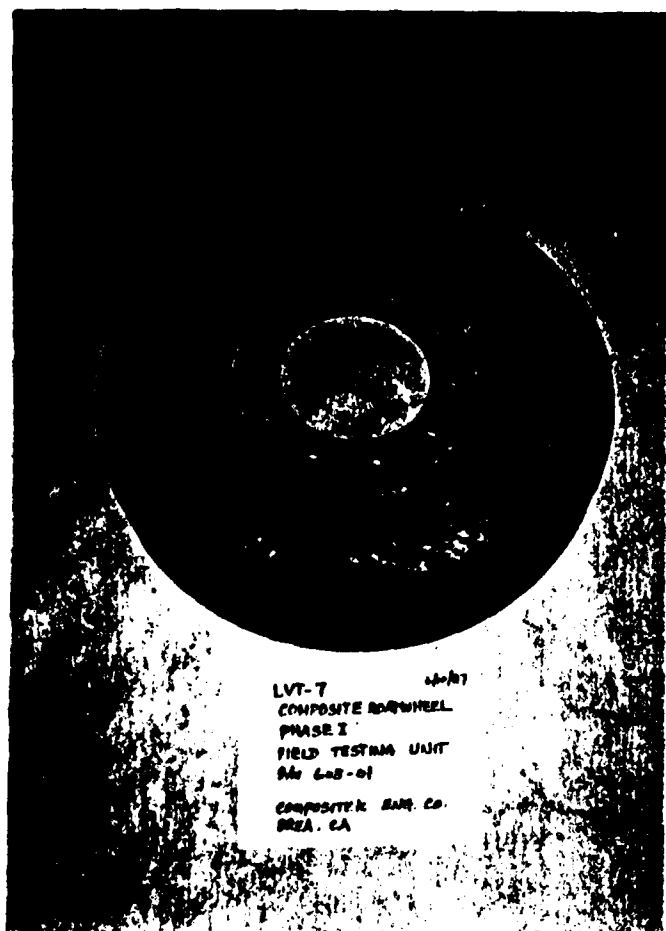


Figure 41. S/N 605-01 after
Field Testing -
outside view,
lost wear plate.

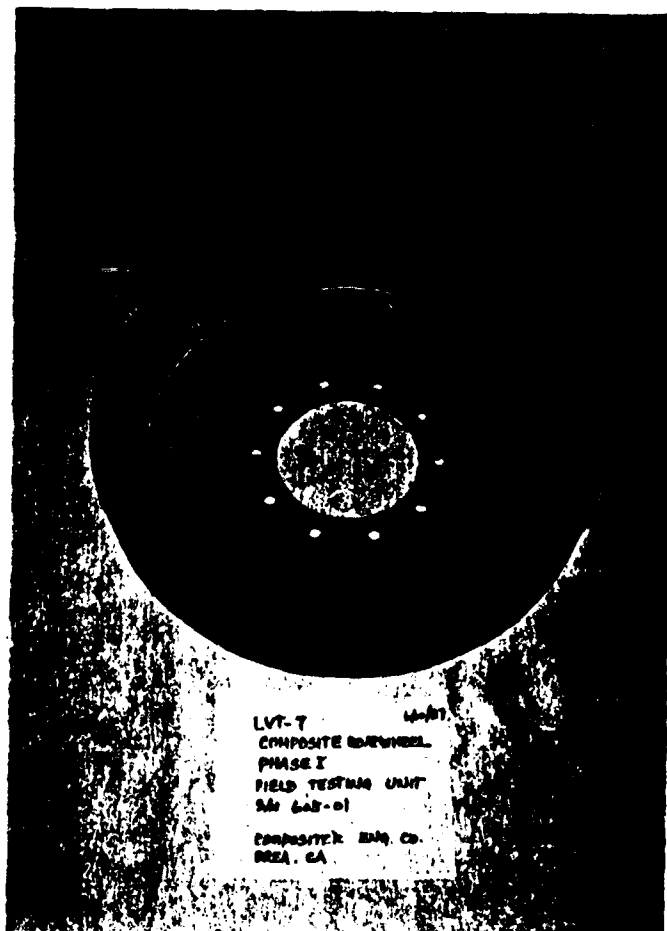


Figure 42. S/N 605-01 after
Field Testing -
inside view.

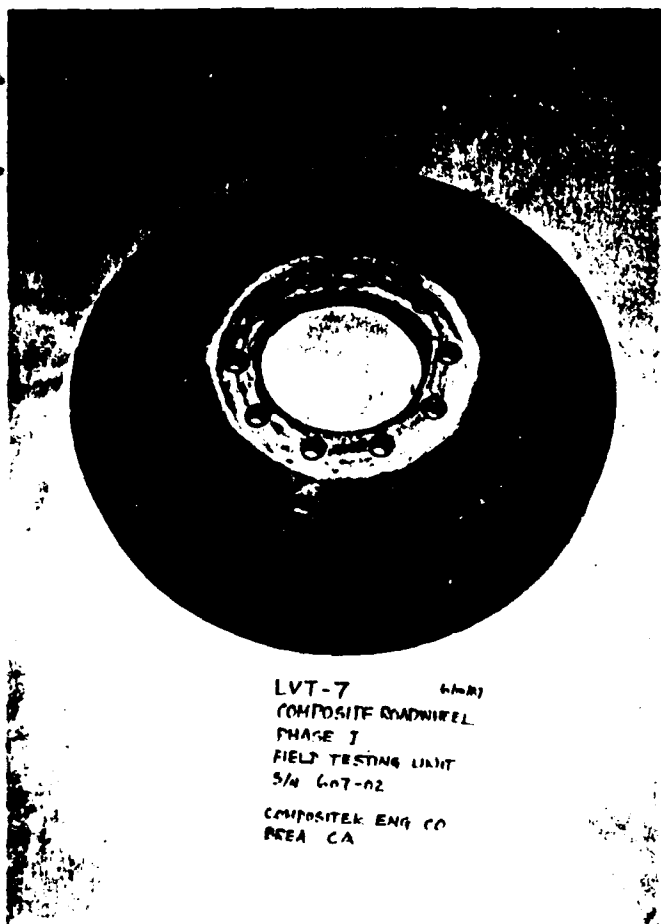


Figure 43. S/N 607-02 after Field Testing - outside view.

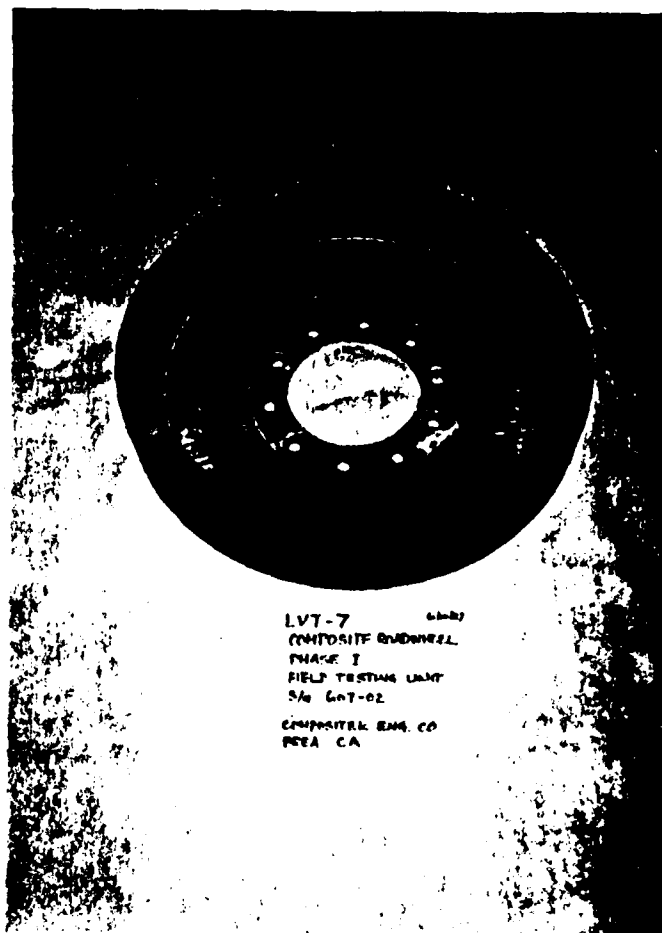


Figure 44. S/N 607-02 after Field Testing - inside view.

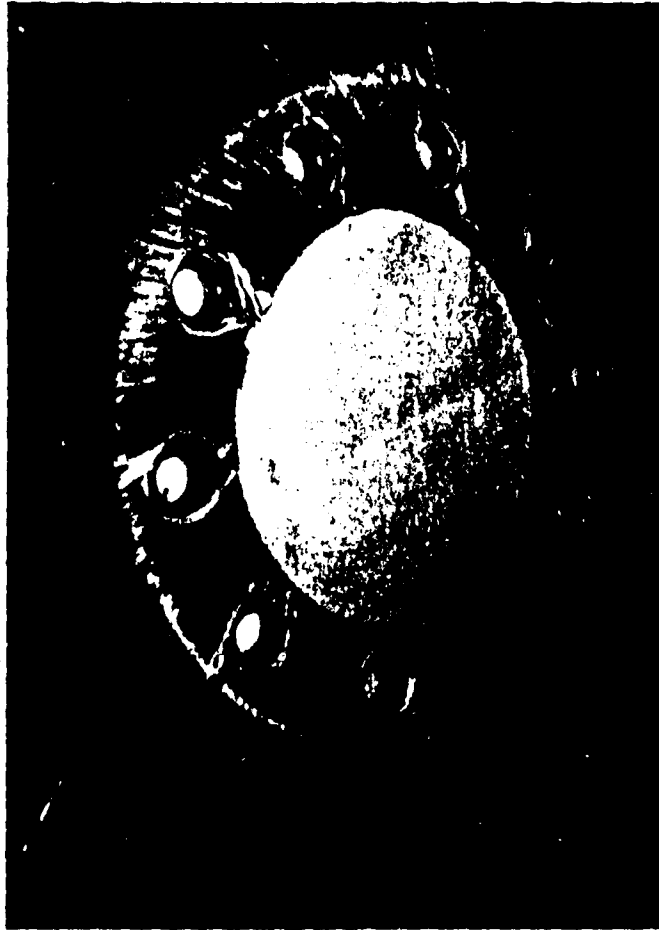


Figure 45. S/N 607-02 after Field Testing -
Delamination at Hub Section.